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A review of geothermal energy resources in Australia: Current status and prospects

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ABSTRACT

Australia has considerable hot rock geothermal energy potential. This results from the widespread occurrence of basement rocks (granites in particular) in which heat is generated by natural radioactive decay. There are extensive areas where temperatures are estimated to reach at least 200 °C at around 5 km depth. In Australia, there is also potential for lower temperature geothermal resources associated with naturally-circulating waters in aquifers deep in a number of sedimentary basins (Hot Sedimentary Aquifer Geothermal). These are potentially suitable for electricity generation and direct use.

This paper will focus on the need to improve geothermal energy utilization in Australia, challenges facing it and the future benefits. This study shows, there is a significant potential for energy savings through greater use of geothermal energy in some regions of Australia.

Contents

1. Introduction

Geothermal energy is an abundant, clean (effectively no greenhouse gas emissions) and reliable (renewable or sustainable) natural resource. The heat is generated by the natural decay over

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millions of years of radiogenic elements including uranium, thorium and potassium. Geothermal power has significant benefits. It is environmentally benign, renewable (temperature is renewed by conduction from adjacent hot rocks, and heat is generated by natural radiogenic decay), and able to provide base-load power and heat for industrial processes. Ground source heat pumps have been proven to be viable in various parts of Australia, and widespread implementation could provide a significant energy efficiency and carbon reduction benefit [1,2,29].

Geothermal resources that have been utilised, or are prospective for development, range from shallow ground to hot water and rock several kilometres below the Earth's surface [1,2].

In the last few years, the concept of geothermal energy has dramatically improved in its development, capabilities and application through the reforming of traditional thought and approaches. The geothermal industry in Australia will attempt to use heat from deep under various unique regions across the country, in order to contribute up to 20% of Australia's electricity capacity [3].

The most compelling feature of geothermal energy process is that it produces zero carbon emissions, potentially making it one of the cleanest sources of energy at our disposal. Another compelling feature is that it can create a constant 24 h base-load power where other renewable energies are unable.

For example, solar energy can only be produced during daylight hours, and is diminished with cloud cover. Similarly, wind turbines are dependent on wind speed which is inherently variable.

Currently, Australian legislations include alternative energy sources as a key tool in reducing carbon emissions and have specific targets such as the Mandatory Renewable Energy Target (MRET) [4–6].

1.1. World geothermal energy

The world has vast, largely unutilised geothermal energy resources. Geothermal energy currently accounts for only a small share of world primary energy consumption.

Geothermal resources are mainly utilised for electricity generation, although direct-use applications are also significant. Globally, geothermal energy use is projected to more than double over the outlook period to 2030 [7,35].

Until recently, geothermal energy was considered to have significant economic potential only in areas with hydrothermal systems; that is, in countries with active volcanoes [8,9,36].

Countries that have identified and are utilising significant amounts of these hydrothermal energy resources include the United States, the Philippines, Indonesia, Mexico, Italy, Iceland, New Zealand and Japan [10–13].

Many countries have identified lower temperature geothermal resources and these are increasingly used for district heating and ground source heat pump systems [14].

Most geothermal plants are built close to the resource because it is generally not efficient to transport high temperature steam or water over distances of more than 10 km by pipeline due to heat losses (or 60 km) in thermally insulated pipelines [15].

In 2007, geothermal energy accounted for around 0.4% of world primary energy consumption (Table 1). World geothermal energy consumption has increased slowly in recent years, at an average rate of 0.6% per year between 2000 and 2007.

In the Organization for Economic Co-operation and Development (OECD) region, geothermal energy accounts for a relatively small share of total primary energy consumption (0.6% in 2008) and growth in recent years has also been very slow (0.4% per year between 2000 and 2008).

Fig. 1 provides information on the world use of geothermal energy as a fuel input to the transformation (or conversion) sector and a fuel input to other industries in direct-use applications, all measured in PJ.

Table 1
Key statistics for the geothermal energy market [15,16].

	Unit	Australia, 2006	Organization for Economic Co-operation and Development, (OECD), 2008	World 2007
Primary energy consumption	PJ	–	1316	2053
Share of total	%	–	0.6	0.4
Average annual growth, since 2000	%	–	0.4	0.6
Electricity out put	TWh	0.0007	40	61.8
Share of total	%		0.4	0.3
Average annual growth, since 2000	%		2.4	2.5
Electricity capacity	MW	0.08	5364	10,300

Table 2
Geothermal projects under development [24–26].

Project	Location	Capacity (MW)	Capital expenditure
Moomba stage 2	South Australia	25	–
Paralana	South Australia	30	$200 million
Penola	South Australia	59	$ 340 million

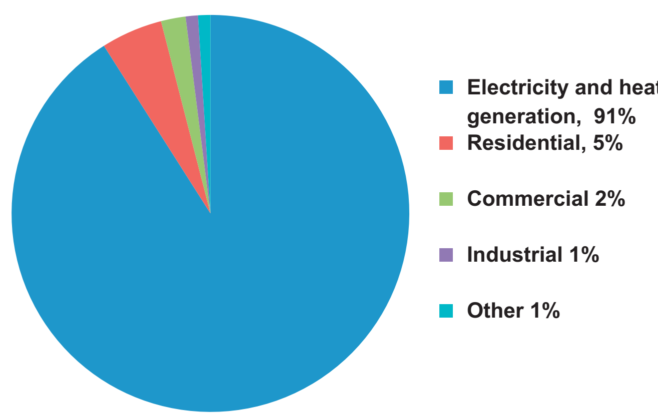

Fig. 1. World geothermal energy consumption, by sector, 2007 [15].

In 2007, 91% of world geothermal energy consumption was used as a fuel input to the transformation sector (of which electricity plants accounted for 97.5% combined heat and power plants for 2.2% and heat plants for 0.3%).

The remaining 9% was used in direct use applications (for district heating, agriculture and greenhouses) including, most importantly, 5% in the residential sector and 2% in the commercial sector [15].

The outlook for the world geothermal energy market to 2030 will focus on electricity generation. However, the increased global demand for renewable energy is expected to increase demand for geothermal energy both for electricity generation and for direct use.

The strong growth in use of ground source heat pumps established over the past decade is expected to continue, supported by increased demand for renewable energy and increasing

cost-effectiveness of direct use geothermal energy. Improvements in drilling technologies, improved reservoir management, and reduced operating and maintenance costs, coupled with further exploration, are likely to promote increased utilisation of geothermal resources, and hydrothermal resources in particular [1–34].

2. Australia's geothermal resources

Australia, while only containing 0.3% of the world's population produces 1.5% of the world's carbon emissions making it one of the highest carbon emitters per capita in the world. As there are no active volcanoes on the Australian continent (there are active volcanoes on Heard and McDonald Islands), Australia lacks conventional hydrothermal resources. However, Australia has substantial potential for Hot Rock and Hot Sedimentary Aquifer resources.

Current knowledge on Australia's geothermal potential is based on a database of temperatures recorded at the bottom of more than 5700 deep drill holes, most of which were drilled for petroleum exploration supported by more detailed local investigations by companies [17].

As of July 2009 eight companies have declared identified geothermal resources totalling 2.6 million PJ of heat in place.

The Australian Bureau of Mineral Resources (BMR) first drew attention to Australia's hot rock potential in the Cooper Basin, other sub-basins beneath the Eromanga Basin (Queensland, New South Wales, South Australia); the McArthur Basin (Queensland/Northern Territory); the Otway Basin (Victoria, South Australia); the Carnarvon, Canning and Perth basins (Western Australia); areas in east Queensland; and the Sydney Basin north-west of Newcastle [18].

In the Cooper Basin, they reported extrapolated temperatures in excess of 300 °C at 5 km depth, and estimated the heat energy available in rocks at temperatures above 195 °C at 7.8 million PJ [18].

The Great Artesian Basin (GAB) is the largest artesian basin in the world covering about 22% of the Australian continent and has ground waters of 30–100 °C at the well head.

The existing geothermal power generation in Australia is a 80 kW net binary-cycle plant at Birdsville in south west Queensland.

This power plant utilises a low-temperature hydrothermal-type geothermal resource, accessing 98 °C groundwater from a 1230 m deep artesian bore that taps a confined aquifer in the underlying Great Artesian Basin [19]. Table 2 shows current geothermal projects under development in Australia.

2.1. Hot rock geothermal resources

Exploration has been largely focused on the high temperature Hot Rock geothermal resources of South Australia (Cooper Basin, Adelaide F old Belt, Mount Painter Inlier–Frome Embayment). Each of these areas has an underlying basement that includes high heat-producing granites of Proterozoic age. The depth of sedimentary cover varies from relatively shallow along the margins of the Mount Painter Inlier to more than 5 km in the Cooper Basin.

2.2. Hot sedimentary aquifer geothermal resources

There are several sedimentary basins in Australia where high geothermal gradients are known, including the Otway Basin (South Australia, Victoria), Gippsland Basin (Victoria), Perth Basin (Western Australia), Carnarvon Basin (Western Australia) and the Great Artesian Basin (Queensland, New South Wales, South Australia, Northern Territory). These basins have porous and permeable aquifers, which means that hot water circulating naturally at depth within them can be readily extracted. However, some fracture enhancement may be necessary to increase flow rates, especially in deeper parts of basins.

This potential has stimulated significant interest in exploration for hot sedimentary Aquifer geothermal resources in a number of basins, notably the Otway, Gippsland and Perth basins. For example, shallow groundwater systems in the Perth Basin are being investigated as a potential source of low temperature energy that could be used for direct heating and other applications. The Otway Basin differs from the other areas in that there is also potential for heat input from dormant volcanic activity that occurred some 5000 years ago. However, previous regional heat-flow data showed no evidence of abnormal heat-flow in the region, including around Mount Gambier — the youngest volcano in the Newer Volcanics group in the south–west Victoria–southeast South Australia region. More detailed heat flow measurements identified a 40 km long zone of elevated heat flow of uncertain origin (including potentially buried granite) along the northern margin of the Otway Basin [37], and highlighted the need for higher resolution data to identify finer scale variations in heat flow [20,21].

2.3. Direct heat geothermal resources

Direct-use applications generally require access to low to moderate geothermal resources with at least moderate flow rates. Direct-use applications such as air conditioning for commercial and office buildings via absorption chillers or making fresh water via seawater distillation desalination will generally require access to Hot Sedimentary Aquifer geothermal resources.

Ground source heat pumps have potential in Australia, although this technology is most cost effective in geographic locations that have marked seasonal temperature fluctuations. Estimating the full resource potential is somewhat difficult — this technology can be applied anywhere, but local conditions and the cost competitiveness of the technology are important factors in influencing its uptake [20,21].

3. Development of a framework for the Australian geothermal industry

At present geothermal energy resources are used only in limited local-scale applications in Australia. High and moderate temperature geothermal energy resources (Hot Rock and Hot Sedimentary Aquifer) may be utilised to produce base-load electricity for distribution through the transmission grid. In addition, lower temperature geothermal energy resources, particularly those found in shallow sedimentary aquifers, could be used for direct-use applications. Ground source heat pumps could be employed almost anywhere and on a range of scales to provide building heating and cooling.

The Australian Geothermal Industry Development Framework and the associated Australian Geothermal Industry Technology Roadmap were released in December 2008 (see Australian Government Department of Resources, Energy and Tourism) [20,21].

Other than at Birdsville, Australia's reported geothermal resources are currently all sub-economic because the commercial viability of utilising geothermal energy for large-scale electricity generation connected to the National Electricity Market has not yet been demonstrated in Australia [20,21].

Australia's geothermal industry is still in the RD&D phase of the technology innovation process.

It is not expected that any technological breakthroughs are needed. Rather there is a need for progression of projects through all stages from resource definition to production and marketing.

Project economics is the main factor that has potential to impede the development of the industry [20,21].

The framework recognised that Australia's geothermal industry is at a very early stage of development and identified major challenges for the future of the industry including the development of:

- an attractive investment environment in which early stage ventures are able to mature to a level sufficient to attract private finance;
- accurate and reliable information on geothermal energy resources in Australia;
- networks that encourage sharing of information and experience between stakeholders including companies, researchers and governments in Australia and overseas;
- geothermal technologies suited to Australian conditions;
- a skilled geothermal workforce;
- community understanding and support of the economic, environmental and social benefits of geothermal energy;
- a geothermal sector which understands and can contribute to the institutional environment within which it operates;
- a consistent, effective and efficient regulatory framework for geothermal energy.

Several recommendations have been significantly advanced already. For example, three key outcomes are:

- The first edition of the Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves.
- The Australian Government's $435 million Renewable Energy Demonstration Program in November 2009 awarded $90 million to Geodynamics Ltd.'s Cooper Basin Commercial Demonstration Program, and $63 million to Petratherm Ltd.'s Paralana project.
- The Australian Government's $50 million Geothermal Drilling Program, administered by the Department of Resources, Energy and Tourism, has provided seven grants of each of $7 million for proof-of-concept projects in Hot Rock and Hot
- Sedimentary Aquifer settings for both electricity generation and direct-use applications.

In addition, the Victorian Energy Technology Incentive Scheme has awarded $25 million to a geothermal project out of a total of $72 million of grants.

The Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves (2008) has been developed to provide a common framework for categorising geothermal resources and reserves for the information of potential investors (available at www.agea.org.au).

The various categories of the Code describe the development process, which broadly consists of reducing geological uncertainty and completing technical (e.g. energy conversion), economic and regulatory requirements [20,21].

4. Australia's geothermal energy market

- Government policies relating to geothermal energy research, development and demonstration (RD&D) are critical to the outlook for electricity generation from geothermal energy. The Australian Government's Renewable Energy Demonstration Program and Geothermal Drilling Program are key contributors.
- There are uncertainties in the outlook for geothermal power over the next two decades. A major uncertainty is the cost of electricity production as the technology has yet to be proven commercially viable. Present estimates show a wide range in the cost of geothermal electricity generation, reflecting the current pre-commercial stage of the industry, as the cost of electricity generation is highly dependent on future technology developments and grid connection issues.
- The geothermal industry in Australia is progressing, with proof-of-concept having been attained in one project and expected to be achieved in at least two others within one to two years. Several pilot projects are expected to be completed within next few years.
- Progress is being assisted by government grants to developing geothermal projects. Two geothermal projects were awarded grants in November 2009 totalling $153 million under the Australian Government's Renewable Energy Demonstration Program; the Australian Government Geothermal Drilling Program has announced $49 million in grants to support seven proof-of-concept projects; and the Victorian Government has announced $25 million to support a demonstration project.
- In ABARE's latest long-term energy projections [25], which include the Renewable Energy Target, a 5% emissions reduction target and other government policies, geothermal electricity generation in Australia is projected to increase by 18.4% per year, to reach around 6 TWh in 2029–30 and account for around 1.5% of total electricity generation.
- The demonstration of the economic viability of the extraction and use of geothermal energy both for electricity generation and direct use is critical to attract the capital investment required.
- Improved information on geothermal energy potential in many parts of Australia — especially new geoscientific data designed to locate regions with temperature anomalies at relatively shallow depths (1–4 km) — would aid definition of geothermal resources and reduce exploration costs.
- There is significant potential for energy savings through greater use of ground source heat pumps in heating and cooling buildings in many regions of Australia [20,21].

4.1. Electricity generation

To date, two geothermal energy projects have been undertaken in Australia that demonstrated geothermal electricity generation technologies in the Great Artesian Basin [19]. In 1986, Mulka Station in South Australia used a hot artesian bore to produce a maximum 20 kW of power. However, as the project utilised a working fluid on the power plant side that was subsequently banned, it has since ceased operation.

Electricity generation from geothermal energy in Australia is currently limited to one pilot power plant producing 80 kW net at Birdsville in south west Queensland. The plant uses a binary-cycle power system, and sources hot (98 °C) waters at relatively shallow depths from the Great Artesian Basin [19].

4.2. Direct-use applications

There are a number of small direct-use applications of geothermal energy resources in Australia. At Portland in Victoria, water from a single well was used for heating several council-operated buildings including council offices, library and hospital for several years. Numerous spas and baths operate in several parts of Australia using warm spring waters.

These include spa developments (Mornington Peninsula, Victoria and Mataranka, Northern Territory), artesian baths (Moree, Lightning Ridge artesian baths, and Pilliga Hot Artesian bore, inland New South Wales) and swimming pool heating (Challenge Stadium, Western Australia). Ground source heat pumps are used in several public buildings, including the Geoscience Australia building in Canberra.

4.2.1. Cost of access to the grid

A potential impediment to the development of some of Australia's geothermal resources for geothermal electricity generation is the distance of some of the resources from existing transmission lines or consumption centres. Most geothermal plants are built at the site of the reservoir since it is not practical to transport geothermal resources over long distances.

High-voltage direct current transmission lines are used because for a given carrying power capacity they have less line loss [22]. Additional power lines must be built if transmission infrastructure does not exist where a geothermal resource is located. Some of Australia's known geothermal resources are located in areas remote from the existing electricity transmission grid.

Geothermal developers pay the direct costs to connect their plant to the grid, and may incur additional transmission related costs, including the construction of new lines, upgrades to existing lines, or new transformers and substations [23].

4.3. Geothermal RD&D and technology development

Further research in the exploration and enhancement of reservoirs and in drilling and power generation technology, particularly for the exploitation of low temperature geothermal resources, will be important in realising potential in this area [7,15,35].

It is important to note that the development of the geothermal industry in Australia is not dependent on major technology breakthroughs — all of the required technology exists from the conventional geothermal and petroleum industries, and to a large degree it is a matter of a trial-and-error learning process in adapting this technology. The challenges in Australian geothermal systems are more about making exploitation more economically viable (for example through cheaper drilling), requiring incremental technological adaptation and development rather than major technological breakthroughs [21].

As many other countries around the world (especially the United States) have very large untapped hot rock geothermal resources there is a technology development push worldwide. Geothermal resources in Hot Sedimentary Aquifer systems are also being brought into production in a number of countries, providing another source of experience and technology developments internationally.

Ground source heat pumps have already been demonstrated to be economically and environmentally beneficial in numerous installations in Australia.

As a consequence of the geothermal industry being new to Australia, only limited research has been conducted to date but this is now developing quickly and it is expected that Australian research capability will continue to grow.

4.4. Environmental considerations

Geothermal energy is generally regarded as one of the most environmentally benign sources of electricity generation.

4.4.1. Air emissions

Geothermal fields in Australia will generally utilise groundwater systems, and will have very few air emissions especially if using a double closed loop system. Some concerns have been raised over radon release; however these are projected to be well within Australian occupational health and safety guidelines [27].

The only emissions created are in building infrastructure (well completion, plant, power lines) which is necessary for all generation technologies. There are no emissions associated with the 'fuel'. Low CO_2 emissions: Binary geothermal power plants (overleaf) could be zero-emission (no CO_2 or oxides of nitrogen and sulphur).

4.4.2. Noise pollution

Geothermal plants produce noise during the exploration drilling and construction phases. With direct-heat applications, noise is usually negligible during operation. Noise from normal operation of power plants generally comes from the cooling tower fans, steam ejector and turbine.

4.4.3. Low environmental impacts

There is no acid rain, mine spoils, open pits, oil spills, radioactive wastes, or damming of rivers due to geothermal energy utilization.

5. Australian government support for geothermal energy research, development and demonstration (RD&D)

Australia's considerable high-temperature (above 180 °C) geothermal energy potential associated with deep Hot Rock resources and lower temperature resources associated with hot waters circulating in aquifers in sedimentary basins (Hot Sedimentary Aquifer resources), have potential for electricity production and direct use. The requirements for development of geothermal electricity generation include significant investment, firstly in demonstration projects to prove viable generation, and then in commercialisation. Government policy and direct support for research, development and demonstration are likely to continue to play a significant role in this process until commercial viability can be established.

Government policies relating to geothermal energy research, development and demonstration (RD&D) are critical to the utlook for electricity generation from geothermal energy in Australia.

Actions to accelerate the development of the geothermal industry include completion of the Australian Geothermal Industry Development Framework and the associated Australian Geothermal Industry Technology Roadmap. Direct assistance includes the Australian Government's $50 million Geothermal Drilling Program, administered by the Department of Resources, Energy and Tourism, which has provided grants of $7 million for seven proof-of-concept projects in Hot Rock and Hot Sedimentary Aquifer settings. The Australian Government has also provided funding to assist two geothermal projects to a total of $153 million to progress from proof-of concept to commercial demonstration stage from its $435 million Renewable Energy Demonstration Program. These programs, which provide funding to projects on a merit-basis, will accelerate the development of the geothermal industry by helping to address the key impediment to development of insufficient market investment.

Australia's existing indicated geothermal resources are sufficient to meet projected domestic demand over the period to 2030. There is also scope for Australia's geothermal resources to expand substantially, based on further predicted temperature at 5 km data [28], heat flow measurements and enhanced general geological knowledge (Fig. 2).

This in turn could affect the market outlook as several expected proof-of-concept projects demonstrate the suitability of the technology to Australia and commercial demonstration projects are established.

6. Conclusions

Geothermal energy is a major resource and potential source of low emissions renewable energy suitable for base-load electricity

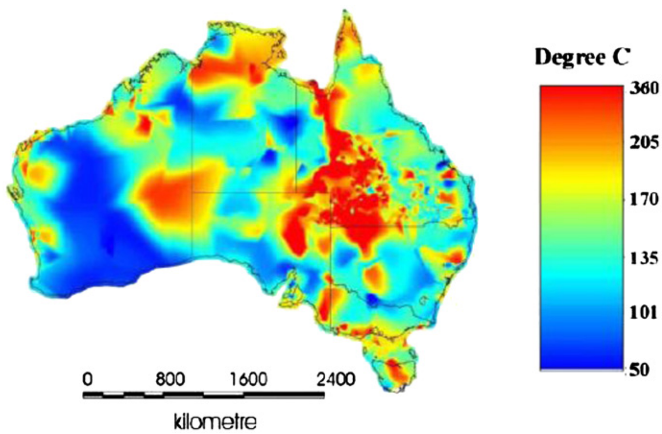

Fig. 2. Subsurface temperature distribution in 5 km depth (Australia) [28].

generation and direct-use applications. Below is a summary of research conclusions point by point:

- Australia has significant potential geothermal resources associated with buried high heat-producing granites and lower temperature geothermal resources associated with naturally-circulating waters in aquifers deep in sedimentary basins.
- Most current geothermal projects in Australia are still at proof-of-concept or early commercial demonstration stage.
- Demonstration of the commercial viability of geothermal energy in Australia will assist in attracting the capital investment required for geothermal energy development. The development of some remote geothermal resources will require additional transmission infrastructure.
- Geothermal energy is projected to produce around 6 TWh in 2029–30. Electricity supply is likely to be from demonstration plants initially but commercial-scale geothermal energy production is expected by 2030.
- The major geothermal energy developments occurring in Australia are focused on electricity generation. Given the major investment in geothermal energy RD&D by both government and industry in Australia, it is considered likely that geothermal power will be produced on a commercial scale over the period to 2030.
- There is considerable uncertainty surrounding projections of geothermal energy in the period to 2030 in Australia. The commercial development of the industry is dependent on the demonstration in Australia of commercial viability to show an acceptable investment risk, and this includes grid connection issues.

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